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Electromagnetic Ultrasonic Probe

Background of the Invention

The present invention relates to an electromagnetic ultrasonic probe for coupling media-free generation and reception of ultrasonic waves in the form of linearly polarisized transverse waves in a workpiece, respectively therefrom. Such a type ultrasonic probe provides a unit which generates ultrasonic waves inside the workpiece having a transmission coil arrangement to which a high-frequency voltage can be applied to generate a high-frequency field: moreover a premagnetizing unit ensures generation of a quasi-static magnetic field superimposing the high-frequency magnetic field in the workpiece. Furthermore, to detect ultrasonic waves, a unit is provided to receive the ultrasonic waves. The ultrasonic reception unit is provided with a reception coil arrangement which can be connected to an evaluation unit.

In order to prevent the filigree transmission coil and reception coil arrangements from suffering mechanical damage due to direct contact with the surface of the workpiece, the arrangements are disposed in a torus-shaped manner on at least one partially toroidally designed magnetic core, which is provided with at least two front ends that can be turned to face the workpiece. The high-frequency magnetic fields can be coupled into, respectively out of, the workpiece via these two front ends, permitting in this manner to dispose the coil arrangements on the surface of the workpiece at a distance from each other. Nonetheless the high-frequency magnetic fields required for the generation and detection of ultrasonic waves inside the workpiece are effectively coupled into, respectively out of, the workpiece via a partially toroidally designed magnetic core.

Such type ultrasonic probes permit generation and reception of linearly polarized transverse waves which are irradiated under the probe perpendicular into the workpiece, respectively are received from this direction and oscillate perpendicular to their propagation direction in a plane. Technical fields of application of such type ultrasonic probes are, for example, nondestructive examination of electrically conductive workpieces for material flaws, such as cracks, in particular perpendicular

to the polarization direction of the ultrasonic waves and crack-like flaws that are oriented parallel to the propagation direction, including other process based on ultrasonic velocity and polarization, such as for example measuring voltage or, in particular, measuring thickness.

Prior Art

The coupling-media-free electromagnetic probes known from the state of the art convert electromagnetic field energies in the elastic energy of an ultrasonic wave and inversely. The conversion mechanism is based on the interaction between the electromagnetic field and an electrically conducting material that moreover a static magnetic field or a quasi-static magnetic field applied from the outside passes through. The term "quasi-static" magnetic field comprises, in addition to the actual static magnetic field, which for example can be generated by means of permanent magnets, also low-frequency magnetic fields, whose alternating frequency is much lower than the high frequency with which the transmission coil arrangement is operated to generate high-frequency fields.

In order to excite ultrasonic waves inside an electrically conducting workpiece, at least one part of the high-frequency magnetic field, whose frequency range lies within the ultrasonic frequency range, and which is generated by the high-frequency coil arrangement, is coupled into the workpiece, thus inducing eddy currents at skin depth which in conjunction with the "quasi-static" magnetic field generate ultrasonic waves due to the Lorentz forces or magnetostrictions occurring inside the workpiece.

Detection of ultrasonic waves occurring inside the workpiece occurs inversely by detection of the electric voltage induced in the reception coil arrangement resulting from high-frequency fields which for their part are generated by the motions of electric charges, due to the ultrasonic waves, in the workpiece inside the "quasi-static" magnetic field.

All prior art electromagnetic ultrasonic transducers are based on the common goal of development to optimize measuring sensitivity and, related thereto, to optimize the signal amplitudes that can be produced by the transmission coil and the reception coil arrangements in the transmission signal and in the reception signal. The aim, on

the one hand, is to design the coupling mechanism with which the generated and to-be-detected high-frequency fields are coupled in and out between the ultrasonic transducer and the workpiece as loss-free as possible and, on the other hand, to select the field strength of the quasi-static magnetic field as large as possible, which is decisive for generating and detecting ultrasonic waves.

DE 42 23 470 C2 describes a generic electromagnetic probe for vertical acoustic irradiation of linearly polarized transverse waves, in which the high-frequency magnetic fields are coupled in and out in a most efficient manner between the probe and the workpiece without, as is the case with many other probes, placing the transmission and reception coils, usually designed as high-frequency air coils, directly on the surface of the workpiece. But rather the electromagnetic probe of figure 2 described in this printed publication is provided with a half-open toroidal tape core 6, made commercially of amorphous tape material, around which a transmission coil arrangement 7 and a reception coil arrangement 8, respectively, are wound. The front ends 11 of the half-open toroidal tape core 6 act as coupling areas for the high-frequency magnetic fields and can be placed in a suited manner on the surface of the to-be-examined workpiece 5. The high-frequency magnetic fields generated by the high-frequency transmission coil arrangement 7 reach via the front ends 11 of the toroidal tape core 6 into the workpiece 5 and are able to induce close-to-the surface eddy currents 12 at skin depth inside the workpiece 5.

The quasi-static magnetic field oriented perpendicular to the surface of the workpiece 5 required for sound conversion is generated by means of two permanent magnets 3 of the same name and is conveyed to the material surface of the workpiece 5 via a soft iron core 2 provided inside the toroidal tape core. The premagnetizing unit required for producing the "quasi-static" magnetic field that is oriented perpendicular to the surface of the workpiece is located inside the open part of the toroidal tape core 1.

A drawback of the aforedescribed embodiment of an electromagnetic probe are the low signal strengths obtainable with this probe for generating and detecting ultrasonic waves. Thus the construction-based low volume of the premagnetizing unit prevents generating high magnetic fluxes.

In addition to the preceding printed publication, DE 36 37 366 A1 and DE 195 49 207 A1 describe probes for nondestructive examination. However, the construction of these probes differs from that of the ones described in the preceding. For instance, DE 36 37 366 A1 presents an electromagnetic ultrasonic transducer, whose high-frequency transmission and reception coil arrangement are placed along a rib-like carrier structure over which a magnetic arrangement for generating the quasi-static magnetic field projects. DE 195 49 207 A1 describes a corresponding probe which is provided with a magnetic field concentrating element but differs in all other details from the device described in the introduction.

Summary of the Invention

The object of the present invention is to further develop a generic electromagnetic ultrasonic probe in such a manner that the linearly polarized transverse waves that can be generated inside a workpiece with the probe have higher signal amplitudes than is the case with hitherto probes. In particular, detection sensitivity of such a type probe should be increased without having to place the high-frequency coil arrangements required for generating and receiving the ultrasonic waves near to the surface of the workpiece.

The solution of the object of the present invention is set forth in claim 1. Advantageous features that further develop the inventive idea are put forth in the subordinate claims.

The present invention is based on the idea of providing a selective possible manner of increasing the construction volume of the premagnetizing unit required for the "quasi-static magnetic field" based on the electromagnetic probe of DE 42 23 470 C2. Enlarging the premagnetizing unit permits increasing the strength of the "quasi-static" magnetic field entering the workpiece perpendicular thereto in such a manner that the Lorentz forces or the magnetostrictions responsible for generating ultrasonic waves inside the workpiece are increased, which ultimately leads to ultrasonic waves of greater amplitude.

Inversely, the construction-based magnetic field enhancement of the "quasi-static" magnetic field entering the workpiece results in the formation of stronger high-frequency fields which are generated by ultrasonic-wave-based charge excursions inside the workpieces in the presence of quasi-static magnetic fields and are coupled into the toroidal tape core via the front ends. These high-frequency fields enable inducing higher electrical voltages into the reception coil arrangement, by means of which the detection sensitivity of the electromagnetic ultrasonic transducer can be improved considerably.

A key element of the invention is that an electromagnetic ultrasonic probe according to the generic part of claim 1 provides a premagnetizing unit which can be contacted directly or indirectly with the workpiece via a contact area. The premagnetizing unit is disposed laterally beside the at least one partially toroidally designed magnetic core, preferably designed in the form of a toroidal tape core, in such a manner that the premagnetizing unit is able to project over the partially toroidally designed magnetic core in a manner perpendicular to the contact area.

Contrary to the aforecited DE 42 23 470 C2, the preferably half open toroidal tape core, due to the arrangement, does not project over the premagnetizing unit, but rather the toroidal tape core is located laterally directly beside the premagnetizing unit without projecting over the premagnetizing unit or even just parts of it in projection to the surface of the workpiece.

In a preferred embodiment, the partially toroidally designed magnetic core built as a toroidal tape core is disposed inclined with regard to its toroidal plane at an angle α to the contact area, with the two front ends of the toroidal tape core facing the workpiece also forming an angle α with the toroidal plane in such a manner that the toroidal tape core lies largely flush via the front ends on the workpiece. The incline of the toroidal plane of the toroidal tape core is preferably formed in such a manner to the contact area that the high-frequency magnetic fields that can be coupled into the workpiece via the front ends extend in the region under the contact area between the premagnetizing unit and the workpiece and in this way interacts with the quasi-static magnetic field inside the workpiece to generate eddy currents.

The lateral arrangement of at least one partially toroidal magnetic core relative to the contact area between the premagnetizing unit and the workpiece permits constructing the premagnetizing unit, for example in the form of one permanent magnet or a multiplicity of permanent magnets, as large as desired, in particular in the vertical extension to the contact area in order to generate a desired strong "quasi static" magnetic field. Dimensioning of the premagnetizing unit is unlimited due to the fact that the ultrasonic transducer arrangement is open upward perpendicular to the contact area. Only handling aspects can limit the size.

Based on the arrangement of an electromagnetic ultrasonic transducer known from DE 42 23 470 C2, a simple embodiment provides for the use of a single toroidal tape core along which both a high-frequency coil arrangement for a transmission unit and a reception unit are wound.

One preferred embodiment, however, provides for two partially toroidally designed magnetic core constructed as toroidal tape cores disposed on opposite sides with regard to the contact area and thus relative to the premagnetizing unit. Due to separate signal conducting and in order to prevent mutual interference of the transmission signals and the reception signals, the transmission coil arrangement and the reception coil arrangement are disposed separate from each other on the toroidal tape cores located opposite the premagnetizing unit. Such a type separate coil arrangement on two separate toroidal tape cores primarily contributes to reducing so-called dead times which occur if the transmission coil arrangement and the reception coil arrangement are disposed on one and the same toroidal tape core. Ultimately this leads to the toroidal tape core being unable to detect reception signals during the short time periods in which the transmission coil arrangement conveys the toroidal tape core into saturation magnetization. If the ultrasonic transducer is utilized, for example for measuring thickness, these saturation effects lead to the occurrence of dead times which are inaccessible for measuring thickness, i.e. due to the temporally immediate succession of transmission signals and reception signals, the reception signals can, due to the saturation effect be detected only following a minimum interval after the transmission signal. Therefore, workpieces must have at least a thickness of 3-4mm to be measured.

In a further preferred embodiment, the arrangement is provided with two pairs of toroidal tape cores disposed orthogonally in relation to each other about the contact area, which preferably is rectangular in shape. In this manner, two linearly polarized transverse wave fields can be generated inside a workpiece with oscillation planes that are oriented perpendicular to each other, respectively. In this manner, material flaws, for example in the form of cracks the course of which are oriented either perpendicular to one or the other oscillation plane, are detected precisely.

For an efficient as possible, i.e. low loss, and concentrated coupling-in of the "quasi-static" magnetic field into the to-be-examined workpiece, a preferred embodiment provides for utilizing two same name permanent magnets which are both at least partially enclosed by a block made of a soft magnetic material. Connected to the block in direction of the workpiece is a concentrator, which, for its part, also contains a soft magnetic material in order to concentrate the magnetic flux on the contact area. The concentrator itself is provided with two different sized surfaces opposite each other. The larger surface of the two is connected to the soft magnetic material workpiece which at least partially encloses the permanent magnets and the smaller one faces the to-be-examined workpiece, which defines the contact area between the premagnetizing unit and the material. As mentioned in the preceding, the contact area is preferably rectangular in shape and along its at least two opposite lateral edges are disposed the toroidal tape cores inclined obliquely to the contact area.

In order to prevent disturbing eddy currents from coupling in due to the generated high-frequency fields inside the concentrator as a result of the proximity to the toroidal tape cores conducting the high-frequency fields, the concentrator is not composed of a homogeneous electrically conducting material but rather of an electrically nonconducting material into which ferromagnetic particles are introduced in a matrix-like manner in order to conduct and to concentrate the magnetic flux or the concentrator is constructed like the magnetic core of a transformer and comprises a multiplicity of stacked metal plates.

Brief Description of the Invention

The present invention is made more apparent in the following using preferred embodiments with reference to the accompanying drawings without the intention of limiting the scope or spirit of the overall inventive idea.

Figs. 1a,b	show a lateral and a front view of an electromagnetic ultrasonic transducer according to the present invention and
Fig. 2	shows a state-of-the-art electromagnetic transducer.

Ways to Carry Out the Invention, Commercial Applicability

Figures 1a and b show a lateral and a front view of a preferred embodiment of an electromagnetic ultrasonic transducer designed according to the present invention comprising a premagnetizing unit V for generating a sufficiently strong static magnetic field 1 which enters the to-be-examined material W in a perpendicular manner. The premagnetizing unit V is provided with two same name permanent magnets 3 which are at least partially enclosed by a soft magnetic material 2, via which the magnetic flux H is introduced into the workpiece 5 perpendicular to its surface via a concentrator 4, which is connected to the material 2,.

The front view of figure 1 shows that the concentrator 4 has a tapered shape tapering toward the contact area 9 between the premagnetizing unit V and the surface of the workpiece, due to which the magnetic flux H conducted inside the concentrator 4 is concentrated on the narrowly confined contact area 9.

A half open toroidal tape core 6 is disposed to the left and to the right of the sides of the concentrator 4. The transmission coil arrangement 7 is placed on one of the toroidal tape cores 6 and the reception coil arrangement 8 on the other. The ring tape cores 6 are inclined toward the contact area 9 with regard to their partially toroidal planes 10 in such a manner that, on the one hand, it is ensured that the premagnetizing unit V can assume any desired construction height perpendicular to the contact area that projects over the toroidal tape core and, on the other hand, the coil arrangements 7,8 are positioned at a distance from the workpiece surface, due to

which they are not subject to any mechanical wear as a result of direct contact with the surface of the workpiece 5.

In order to ensure that the high-frequency magnetic fields can be coupled in from, respectively to, the individual high-frequency coil arrangements 7,8 largely with no losses into the workpiece 5 via the surface of the workpiece, the front ends 11 of the the toroidal tape cores 6 form with the respective partially toroidal plane 10 an angle α as well, which can fundamentally be selected between 0° and 90°, preferably however is between 30° and 60°. In this manner it is ensured that, despite the inclined position of the toroidal tape cores 6, the front ends 11 lie flush to the sides of the contact area 9 on the surface of the workpiece 5, permitting coupling in and out of the high-frequency magnetic fields largely without losses.

To trigger the ultrasonic waves, the transmission coil arrangement 7, which is usually connected to a high-frequency generator, is fed a high-frequency current burst signal. The magnetic alternative flux H_w generated by the transmission coil arrangement 7 reaches into the workpiece 5 via the toroidal tape core 6 and via a small air gap enclosed between the front ends 11 and the surface of the workpiece 5. A spatially homogenous magnetic alternating field H_w forms at skin depth in the workpiece between the front ends 11 of the toroidal tape core bearing the transmission coil arrangement 7. The eddy currents coupled with the magnetic alternating field H_w inside the workpiece 5 are superimposed by the magnetic field entering the workpiece 5 perpendicularly via the concentrator 4, thereby generating, due to the forming Lorentz forces and magnetostricitions, ultrasonic waves oscillating perpendicular to the direction of the eddy currents and propagating perpendicular to the surface of the workpiece, respectively to the contact area 9. The arrow representations indicate the oscillation direction S and the propagation direction A.

The reception mechanism for detecting the ultrasonic waves propagating inside the workpiece is based on the inverse effect, notably the sound particle velocity developing inside the workpiece of the ultrasonic wave returning to the probe, in interaction with the static magnetic field, generates an electrical field, which conducted via the toroidal tape core 6 to the reception coil arrangement 8 induces an electrical voltage therein. The electrical voltage induced in the reception coil

arrangement 8 can usually be amplified with a downstream amplifier and correspondingly evaluated with an evaluation unit.

Thus the electromagnetic ultrasonic transducer designed according to the present invention combines the advantages relating to loss-free as possible coupling-in and coupling-out of high-frequency magnetic fields required for generation, respectively detection, into, respectively out of, the to-be-examined workpiece. For this purpose, the coil arrangements required for generation and reception are disposed at a distance from the surface of the workpiece in an advantageous manner so that they are not subject to any mechanical wear. Moreover, the arrangement designed according to the present invention offers almost any desired dimensioning of the premagnetizing unit in order to optimize the magnetic field strength of the "quasi-static" magnetic field as desired. This measure ultimately leads to generating greater signal amplitudes for producing stronger ultrasonic waves inside the workpiece, thereby permitting decisively improving the detection sensitivity of the electromagnetic ultrasonic transducer. Dimensioning of the premagnetizing unit is only limited by handling concerns.

List of References

1 “quasi-static” magnetic field

2 soft magnetic material

3 permanent magnets

4 concentrator

5 workpiece

6 toroidal tape core

7 transmission coil arrangement

8 reception coil arrangement

9 contact area

10 partially toroidal plane

11 front end

12 eddy current

S oscillation direction

V premagnetizing unit

A propagation direction